Deducing Air-Sea Fluxes from CBLAST Dropwindsonde Data

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Award Number: N00014-05-1-0323
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LONG-TERM GOALS

Our ultimate objective is to understand and be able to predict changes in the intensities of hurricanes. Over the last three decades, there has been considerable improvement in both our understanding and our ability to predict the tracks of hurricanes, but there is, by contrast, little skill in predicting hurricane intensity change.

OBJECTIVES

The objective of the work carried out under this grant was to understand and be able to model fluxes of enthalpy, moisture and momentum between the ocean and atmosphere in all ranges of wind speed, up to and including wind speeds encountered in severe hurricanes. Modeling such fluxes is critical to predicting hurricane intensity.

APPROACH

Our approach has been to use atmospheric measurements collected in actual hurricanes to deduce surface fluxes of enthalpy and momentum. This was done under the auspices of ONR's Coupled Boundary Layer and Air-Sea Transfer Experiment (CBLAST). These measurements consisted of wind, temperature and humidity measured directly from research reconnaissance aircraft and from GPS dropwindsondes deployed from those aircraft. Such measurements were first used to construct the azimuthally averaged radius-height distributions of angular momentum, moist static energy and radial velocity. Then, assuming that the storm is in an approximately steady state, the radial advections of moist static energy and angular momentum were calculated, and the surface fluxes of angular momentum and enthalpy deduced as those needed to maintain a steady state. This approach had been taken (for angular momentum only) by (Hawkins and Rubsam, 1968), but they had to rely on measurements somewhat inferior to those made during CBLAST. Our work was carried out under the leadership of the principal investigators Kerry Emanuel of MIT, who supervised the analysis of the aircraft and dropwindsonde data, and Peter Black of the NOAA/AOML Hurricane Research Division,

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2005**	2. REPORT TYPE	3. DATES COVERED **00-00-2005 to 00-00-2005**

4. TITLE AND SUBTITLE **Deducing Air-Sea Fluxes from CBLAST Dropwindsonde Data**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **MIT, Room 54-1620,77 Massachusetts Avenue,Cambridge,MA,02139**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT
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15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

who provided the aircraft data and used the early results of our research to plan field operations during the second and third years. Analysis of the aircraft and sonde data is ongoing. This Annual Report covers the researched performed by P.I. Kerry Emanuel.

WORK COMPLETED

During the first year of the project, we completed an analysis of pre-CBLAST aircraft and GPS dropwindsonde data and published the results as a Master's Thesis (Ramstrom, 2001). During the second year, we conducted a preliminary field campaign in which we tested our strategy for deploying a dense line of GPS dropwindsondes across the eyewalls of Atlantic hurricanes, coupled with detailed aircraft measurements of turbulent fluxes across the top of the inflow layer. We obtained one good case of dense eyewall measurements in a strong, nearly axisymmetric storm (Isidore). The third year was devoted to the intensive CBLAST field campaign, during which very dense radial arrays of GPS dropsondes were deployed in two mature, intense hurricanes: Fabian and Isabel. Analysis was begun of these dropwindsonde data.

RESULTS

We have some preliminary results from several traverses of the eyewall of Hurricane Isabel of 2003. In the course of these analyses, we continued to grapple with the problem of locating the axis of symmetry of the eyewall, to which the results are very sensitive. We do not consider this problem solved, and are continuing to work on it. Figure 1 shows the trajectories of dropwindsondes deployed by one of the NOAA WP-3D aircraft in Hurricane Isabel.

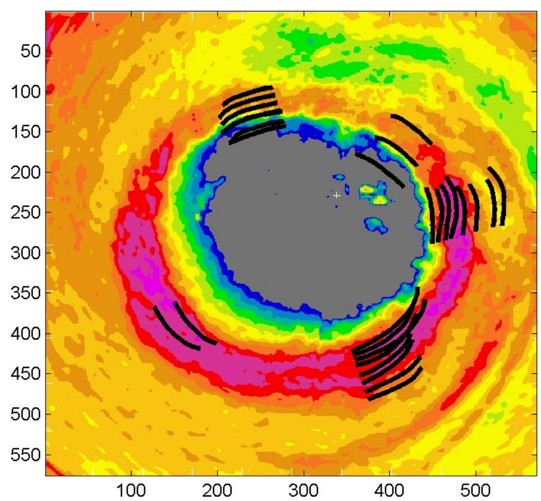

Figure 1: Radar reflectivity in Hurricane Isabel of 2003, with trajectories of dropwindsondes shown in black

We have experimented with several different objective analysis schemes for interpolating the data in space and time to a uniform grid in the radius-altitude plane. Figure 2 shows the mass streamfunction and absolute angular momentum for a single radial pass in Hurricane Isabel.

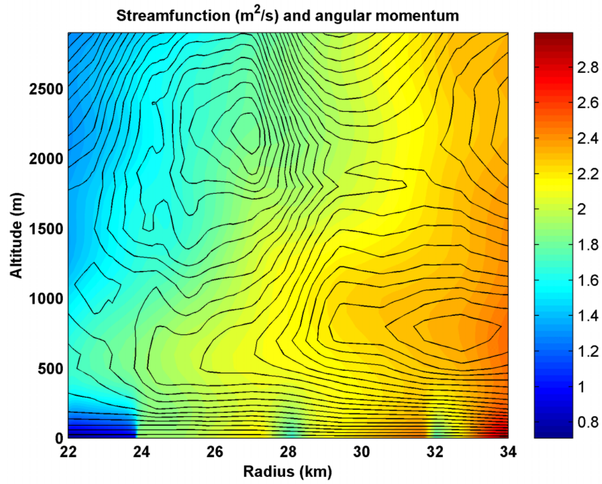

Figure 2: Mass streamfunction (black) and absolute angular momentum per unit mass (coloring) for a single pass through Hurricane Isabel. The flow is parallel to the streamlines, from right to left at bottom of image

We are not yet to the point of being able to construct composite fields over many aircraft passes, but we have made preliminary estimates of the enthalpy and momentum exchange coefficients. Our best current estimate of the drag coefficient is :

$$C_D = 0.0029 \pm 0.0005$$

while our estimate of the enthalpy exchange coefficient is:

$$C_k = 0.0034 \pm 0.0016$$

These are both relevant to a gradient wind of 75 m/s. The large errors bars on the estimate of the enthalpy exchange coefficient reflect various problems with the analysis, including lack of high-resolution aircraft data for estimating the turbulent enthalpy flux out of the boundary layer and inferior objective analysis techniques. We are working on rectifying both these issues.

IMPACT/APPLICATIONS

It is too soon to predict how the results obtained thus far will influence science, but as mentioned above, they had a strong effect on the design and execution of CBLAST. We expect to produce the first truly definitive estimates of exchange coefficients at hurricane wind speeds as the analysis progresses.

TRANSITIONS

The results were used in CBLAST planning.

RELATED PROJECTS

One of the P.I.s (Emanuel) conducted a series of experiments with an annular wind-wave flume. Equivalent 10 m winds speeds of 70 m s^{-1} were achieved in this flume. By measuring the rate of spin down of the water mass after the airflow has been shut down, one can deduce rather precisely the drag coefficient. Similarly, the enthalpy flux coefficient is estimated by measuring the rate at which the

water must be heated to keep it at room temperature. These experiments have shown that the drag coefficient increases linearly with wind speed up to about 30 m s^{-1}, but then levels off with no further increase. Experiments to deduce the enthalpy flux show a similar leveling off of the exchange coefficient at high wind speed.

Working with Ed Andreas, Emanuel has explored the effect of parameterized fluxes of momentum and enthalpy owing to sea spray on numerical simulations of tropical cyclones. This work has been published (Andreas and Emanuel, 2001).

Based on the findings of the first year's research and on the aforementioned flume experiments, the first PI published a theoretical paper presenting a similarity theory for air-sea fluxes at very high wind speeds (Emanuel, 2003).

SUMMARY

We used aircraft measurements of wind, temperature and humidity in several hurricanes to deduce the drag that hurricane winds exert on the ocean surface, and the evaporation of seawater into a hurricane, which is the process that fuels the storm. Understanding the drag and the evaporation is crucial for understanding and predicting changes in hurricane wind speeds. While the estimates we made in this first year of the project are useful and consistent with independent estimates, their primary value was in designing a campaign for making much better measurements in hurricanes, which we began doing during 2002 hurricane season and continued during CBLAST. While we have been able to make preliminary estimates of the surface fluxes from a few passes in one of the two 2003 storms surveyed, we have much more work to do to obtain confidence in such estimates.

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